



## Very low losses for TM polarized light in photonic crystal waveguides

**Borel, Peter Ingo; Frandsen, Lars Hagedorn; Thorhauge, Morten; Boltasseva, Alexandra; Cheng, J.; Kampanis, M.; Kristensen, Martin; Lavrinenko, Andrei; Rechendorff, Kristian; Jacobsen, Rune Shim**

*Total number of authors:*

11

*Published in:*

Quantum electronics and Laser Science (QELS);

*Link to article, DOI:*

[10.1109/CLEO.2003.1298159](https://doi.org/10.1109/CLEO.2003.1298159)

*Publication date:*

2003

*Document Version*

Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

*Citation (APA):*

Borel, P. I., Frandsen, L. H., Thorhauge, M., Boltasseva, A., Cheng, J., Kampanis, M., Kristensen, M., Lavrinenko, A., Rechendorff, K., Jacobsen, R. S., & Zhuang, Y. (2003). Very low losses for TM polarized light in photonic crystal waveguides. In *Quantum electronics and Laser Science (QELS)*; (Vol. 89, pp. JWC3/1-JWC3/2). IEEE. Trends in Optics and Photonics Series Vol. 89 <https://doi.org/10.1109/CLEO.2003.1298159>

---

### General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

# Very low losses for TM polarized light in photonic crystal waveguides

P.I. Borel, L.H. Frandsen, M. Thorhauge, A. Boltasseva, J. Cheng, M. Kampanis, M. Kristensen,

A. Lavrinenko, K. Rechendorff, R. Shim, Y. Zhuang

Research Center COM, Technical University of Denmark, Building 345 west, DK-2800, Kgs. Lyngby, Denmark  
+45 4525 6352 (phone), +45 4593 65 81 (fax), [pib@com.dtu.dk](mailto:pib@com.dtu.dk) (e-mail)

H.M.H. Chong

Department of Electronics and Electronics and Electrical Engineering, Glasgow University, Glasgow G12 8LT, Scotland, UK

**Abstract:** Straight photonic crystal waveguides have been fabricated. Experimentally observed transmission spectra for TE and TM polarizations agree very well with 3D-FDTD simulations. Very low coupling and propagation losses are observed for the TM polarization.

©2002 Optical Society of America

**OCIS codes:** (130.3120) Integrated optics devices; (130.3130) Integrated optics materials; (220.4610) Optical fabrication; (220.4830) Optical systems design; (230.3990) Microstructure devices; (230.7390) Planar waveguides; (230.5440) Polarization-sensitive devices; (999.9999) Photonic crystals

The recent progress in the design of photonic crystal waveguides (PCWs) has paved the way for exploitation of low-loss propagation in real 2D-patterned PCWs [1,2]. The next natural step is to deepen the knowledge of the physics of the PCW enabling the implementation of PCW-based integrated circuits. One particularly important goal is to determine the useful bandwidth of the photonic crystal guiding effect by comparing numerical calculations with experimental transmission spectra.

Seven straight PCWs of lengths 10-150  $\mu\text{m}$  consisting of perforated  $\text{SiO}_2/\text{Si}/\text{SiO}_2$  trilayer films were fabricated as described in [1]. Holes with diameter  $D_{\text{glass}}=0.76\lambda$  were arranged in a triangular array with lattice constant  $\Lambda=428\text{nm}$ . Single rows of missing holes defined the PCWs as shown in Fig. 1.

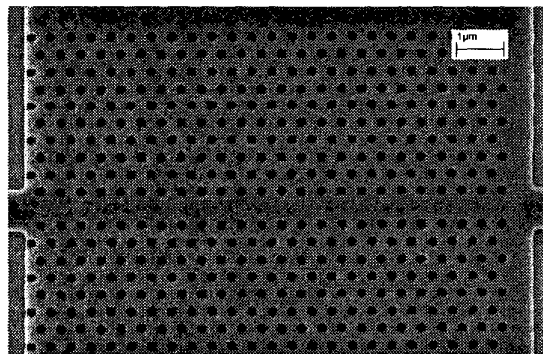


Fig. 1. SEM image of a PCW.

Tapered lensed fibers were used to couple light in and out of the ridge waveguides connected to the PCWs. The light sources were broadband LEDs centered at 1310nm and 1550nm. Transmission spectra were collected with an optical spectrum analyzer and normalized to ridge waveguide measurements.

3D-FDTD calculations of transmission spectra for TE and TM polarizations for four straight PCWs of lengths 29-59  $\Lambda$  were performed using an improved version of the ONYX-2 code [3]. The output light intensity of the PCW was normalized to the entrance light intensity.

Fig. 2 shows the measured transmission through a 10  $\mu\text{m}$  straight PCW for TE and TM polarizations. Also shown are 3D-FDTD calculations for a PCW of similar length. The 3D-FDTD calculations successfully explain all essential features of the spectra as well as the actual transmission level. The position of the sharp cut-off for the TE polarization at longer wavelength is in excellent agreement with previous band gap calculations [1]. The small frequency shift (approximately 2%) between the experimental and simulated spectra is due to the 25nm grid resolution of the 3D-FDTD calculations.

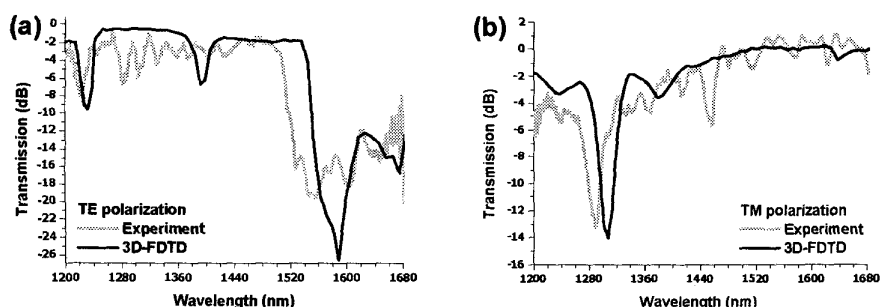


Fig. 2. Measured and calculated transmission through a 10  $\mu\text{m}$  PCW.

Fig. 3 displays the measured and calculated propagation losses for TE and TM polarized light. The losses are extracted by calculating the slope of the measured transmission as function of PCW length. The average coupling loss between the PCW and a connecting ridge waveguide is found to be  $0.07 \pm 0.39\text{dB}$  for the experimental data and  $0.06 \pm 0.27\text{dB}$  for the 3D-FDTD data. Thus, the transmission levels shown in Fig. 2 are essentially due to the propagation losses through the PCWs. In Fig. 3 the displayed wavelength range has been chosen to highlight the lowest loss regions for each polarization, i.e., the usable regions for future applications of PCWs.

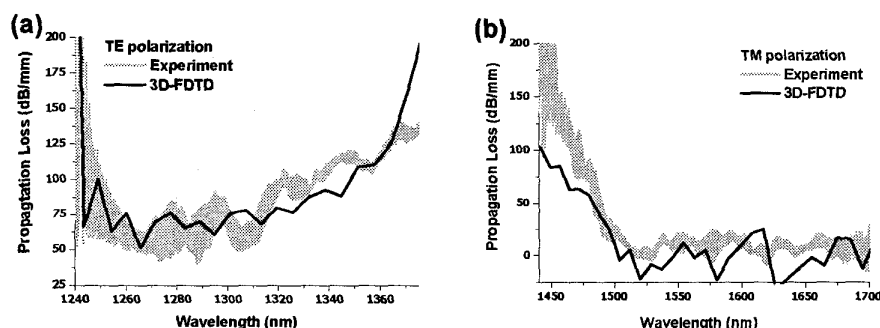


Fig. 3. Measured and calculated propagation losses.

Again excellent agreement is seen between experiment and simulation. Especially noteworthy is the 200nm bandwidth with propagation losses around  $9 \pm 5\text{dB/mm}$  for the TM polarization.

Band calculations show that the very low propagation losses for the TM polarization take place below the valence band. Further experiments have shown that TM polarized light is well-guided through more complicated PCW structures such as couplers and sharp bends. The wavelength range of the low loss TM mode propagation overlaps one of the TE photonic band-gap modes; this may be employed to design polarization independent PCW components.

J. Arentoft, T. Søndergaard, M. Kristensen, A. Boltasseva, M. Thorhauge, and L. Frandsen, "Low-loss silicon-on-insulator photonic crystal waveguides," *Electron. Lett.* **38**, 274-275 (2002).

M. Notomi, A. Shinya, K. Yamada, J. Takahashi, C. Takahashi, and I. Yokohama, "Singlemode transmission within photonic bandgap of width-varied single-line-defect photonic crystal waveguides on SOI substrates," *Electron. Lett.* **37**, 293-295 (2001).

A.J. Ward and J.B. Pendry, "A program for calculating photonic band structures, Green's functions and transmission/reflection coefficients using a non-orthogonal FDTD method", *Comp. Phys. Com.* **128**, 590-621 (2000).